Two world views

FP: functions that perform some operation

OOP: classes that give behavior to some kind of data

Which is better? Depends on software evolution, taste.

Can awkwardly emulate each other

Adapted from material by Dan Grossman.

Common pattern: *expressions*

Operations over type of data

Variants of a type of data

	`eval`	`toString`	`usesX`	…
`VarX`				
`Sine`				
`Times`				
…				

FP: behavior by operation

Function per operation with branch per variant

	`eval`	`toString`	`usesX`	…
`VarX`	🟨	🟦	🟩	
`Sine`	🟨	🟦	🟩	
`Times`	🟨	🟦	🟩	
…	🟨	🟦	🟩	

Datatype with constructor per variant

Pattern-matching selects variant.
Wildcard can merge rows in a function.

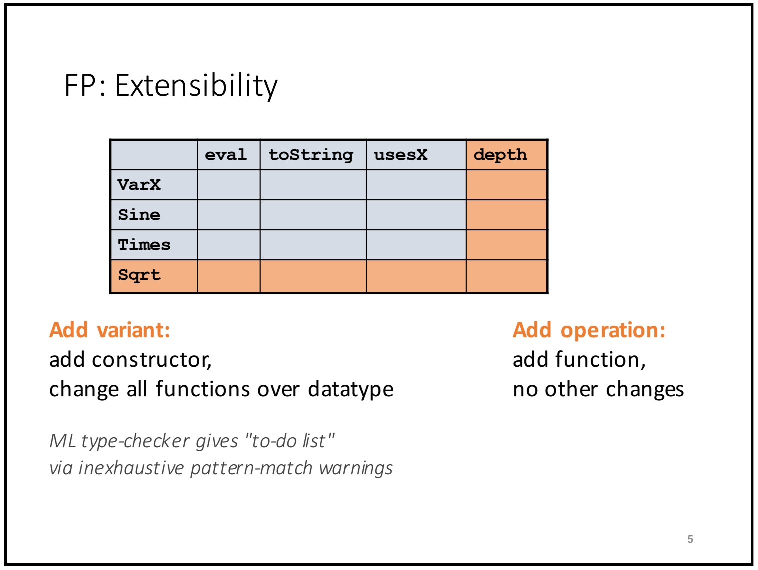
OOP: behavior by variant

Base class with (abstract) **method per operation**

	`eval`	`toString`	`usesX`	…
`VarX`	🟨	🟨	🟨	🟨
`Sine`	🟦	🟦	🟦	🟦
`Times`	🟩	🟩	🟩	🟩
…				

Subclass per variant overrides each operation method to implement variant's behavior

Dynamic dispatch selects variant.
Concrete method in base class can merge rows where not overridden.



FP: Extensibility

	eval	toString	usesX	depth
VarX				
Sine				
Times				
Sqrt				

Add variant:
add constructor,
change all functions over datatype

Add operation:
add function,
no other changes

ML type-checker gives "to-do list" via inexhaustive pattern-match warnings

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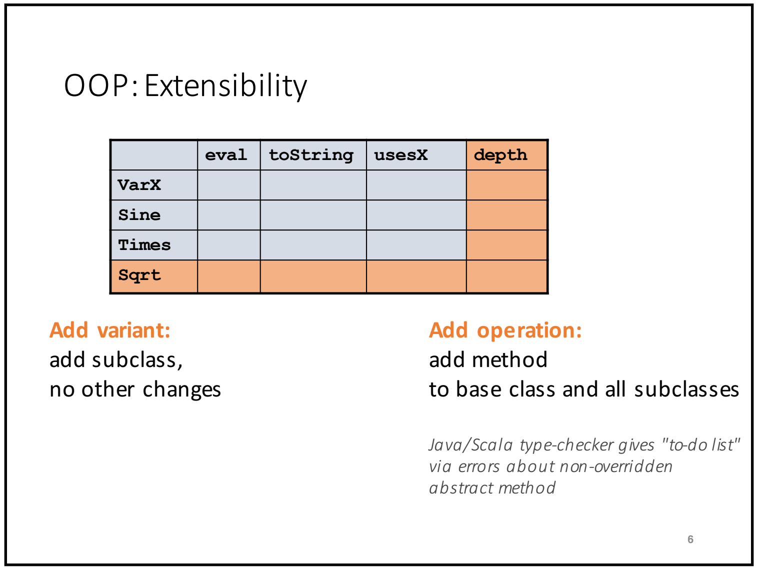

OOP: Extensibility

	eval	toString	usesX	depth
VarX				
Sine				
Times				
Sqrt				

Add variant:
add subclass,
no other changes

Add operation:
add method
to base class and all subclasses

Java/Scala type-checker gives "to-do list" via errors about non-overridden abstract method

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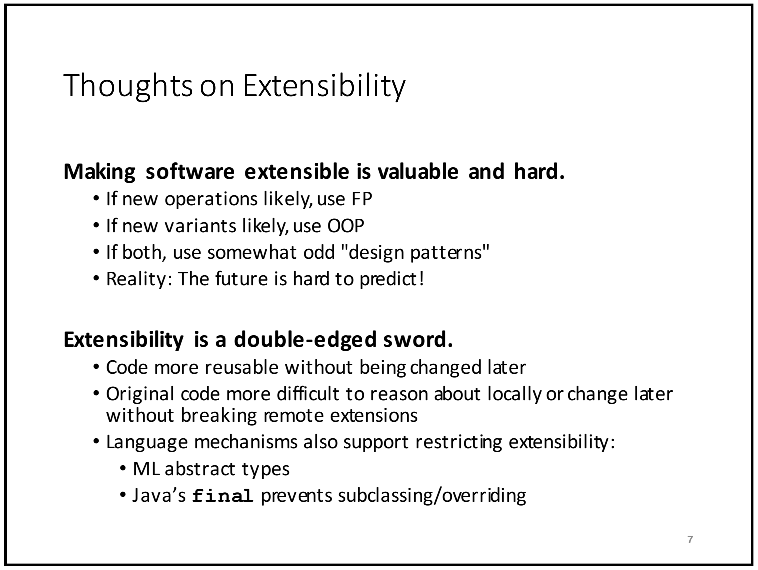

Thoughts on Extensibility

Making software extensible is valuable and hard.

- If new operations likely, use FP
- If new variants likely, use OOP
- If both, use somewhat odd "design patterns"
- Reality: The future is hard to predict!

Extensibility is a double-edged sword.

- Code more reusable without being changed later
- Original code more difficult to reason about locally or change later without breaking remote extensions
- Language mechanisms also support restricting extensibility:
  - ML abstract types
  - Java's `final` prevents subclassing/overriding

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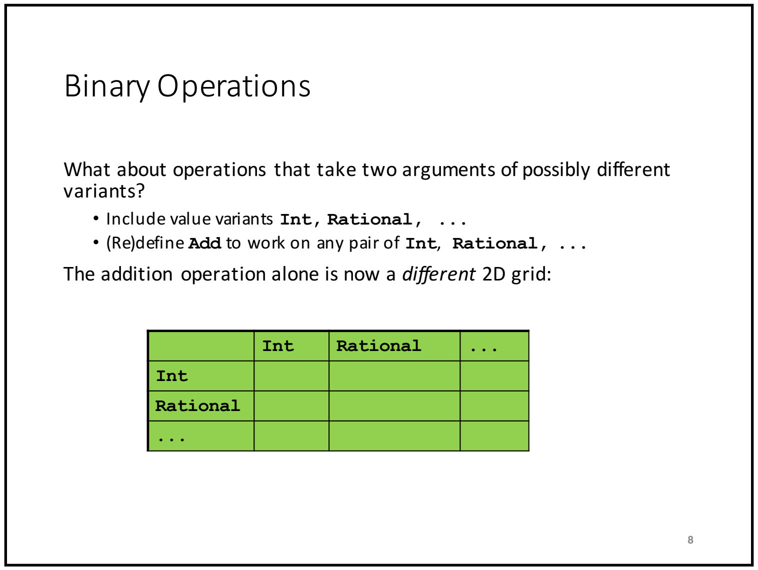

Binary Operations

What about operations that take two arguments of possibly different variants?

- Include value variants `Int`, `Rational`, `...`
- (Re)define `Add` to work on any pair of `Int`, `Rational`, `...`

The addition operation alone is now a *different* 2D grid:

	Int	Rational	...
Int			
Rational			
...			

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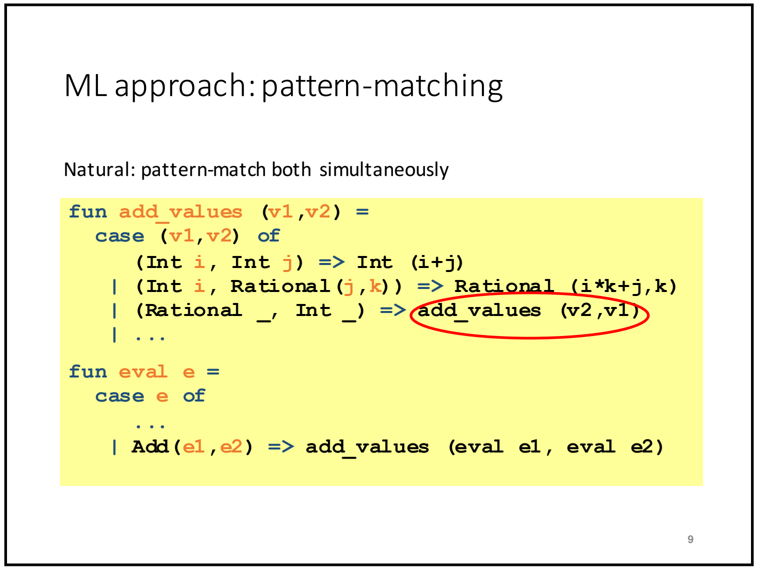
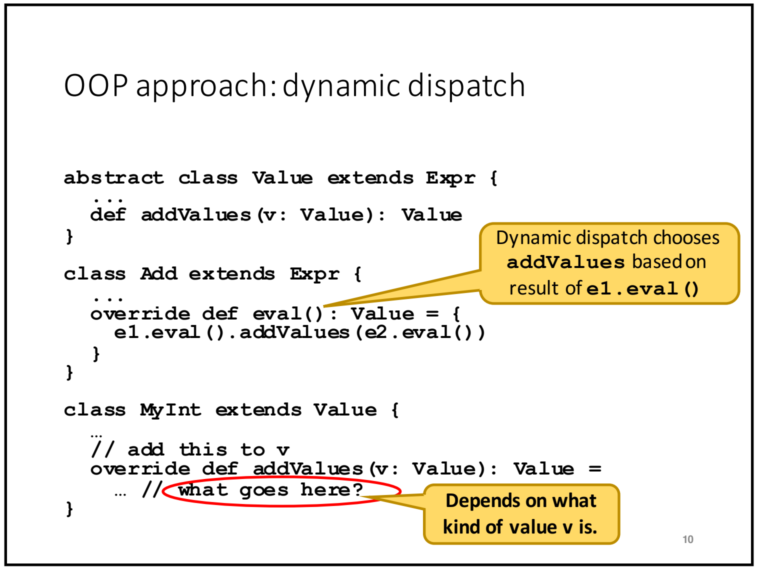


ML approach: pattern-matching

Natural: pattern-match both simultaneously

```
fun add_values (v1,v2) =
  case (v1,v2) of
     (Int i, Int j) => Int (i+j)
   | (Int i, Rational(j,k)) => Rational (i*k+j,k)
   | (Rational _, Int _) => add_values (v2,v1)
   | ...

fun eval e =
  case e of
     ...
   | Add(e1,e2) => add_values (eval e1, eval e2)
```

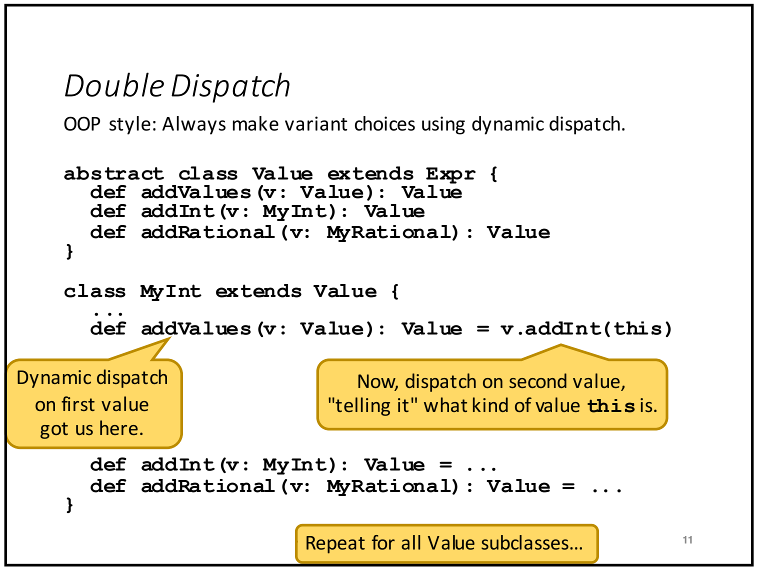


OOP approach: dynamic dispatch

```
abstract class Value extends Expr {
  ...
  def addValues(v: Value): Value
}

class Add extends Expr {
  ...
  override def eval(): Value = {
    e1.eval().addValues(e2.eval())
  }
}

class MyInt extends Value {
  …
  // add this to v
  override def addValues(v: Value): Value =
    … // what goes here?
}
```

Dynamic dispatch chooses **addValues** based on result of **e1.eval()**

Depends on what kind of value v is.



Double Dispatch

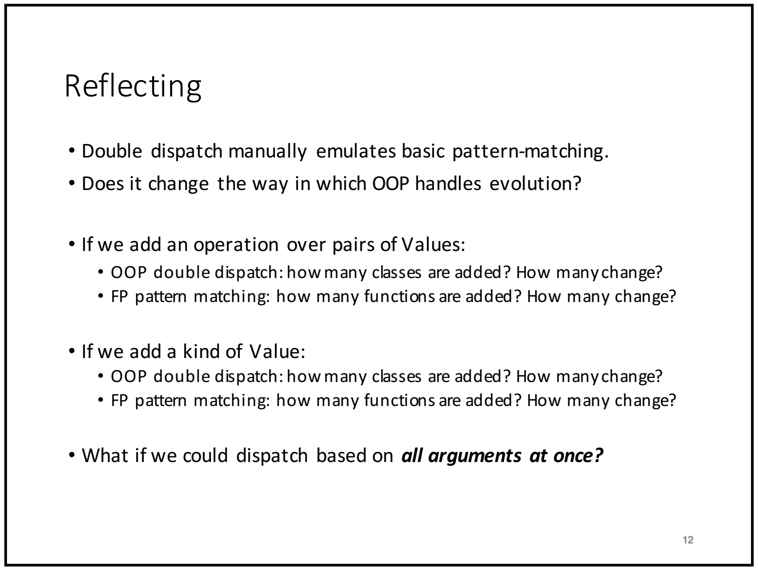
OOP style: Always make variant choices using dynamic dispatch.

```
abstract class Value extends Expr {
  def addValues(v: Value): Value
  def addInt(v: MyInt): Value
  def addRational(v: MyRational): Value
}

class MyInt extends Value {
  ...
  def addValues(v: Value): Value = v.addInt(this)

  def addInt(v: MyInt): Value = ...
  def addRational(v: MyRational): Value = ...
}
```

Dynamic dispatch on first value got us here.

Now, dispatch on second value, "telling it" what kind of value **this** is.

Repeat for all Value subclasses…



Reflecting

- Double dispatch manually emulates basic pattern-matching.
- Does it change the way in which OOP handles evolution?

- If we add an operation over pairs of Values:
  - OOP double dispatch: how many classes are added? How many change?
  - FP pattern matching: how many functions are added? How many change?

- If we add a kind of Value:
  - OOP double dispatch: how many classes are added? How many change?
  - FP pattern matching: how many functions are added? How many change?

- What if we could dispatch based on ***all arguments at once?***

Multimethods

General idea:

- Allow multiple methods with same name and # arguments
- Indicate which ones take instances of which classes
- Use dynamic dispatch on all arguments in addition to receiver to pick which method is called
- NOT same as static overloading.

If dynamic dispatch is essence of OOP, this is cleaner, more OOP

Downside:

subclassing sometimes causes "no clear winner" for which method to call

Research idea picked up in some recent languages (e.g., Clojure, Julia)

The other way is possible with planning.

- Functions allow new operations and objects allow new variants without modifying existing code ***even if they didn't plan for it.***
- Functions can support new variants "if they plan ahead"
  - *Use type constructors to make datatypes extensible*
  - *Operations use function argument to give result for extension*
- Objects can support new operations "if they plan ahead"
  - ***Visitor Pattern** uses double dispatch to allow new operations "on the side"*
  - *See assignment.*
- Neither "plan ahead" option is elegant, but they work.

Closures vs. Objects

Closure:

- Captures code of function, by function definition.
- Captures all bindings the code may use, by lexical scope of definition.

Object:

- Captures code for all methods that could be called on it, by class hierarchy.
- Captures bindings that may be used by that code, by instance variables declared in class hierarchy.

Emulation in both directions is fascinating.